ADVANCED COOLING TECHNOLOGIES, INC.

Company and Technology Overview

Agenda

→ **Company Overview:**

- Basics
- Relationship with Thermacore
- Personnel Achievements & Technology Development
- Key Technologies and Products

→ **Technology Highlights:**

- High Performance Heat Pipes and Evaporators
- High Heat Flux Oscillating Flow Loops
- Alkali Metal Heat Pipes and Loop Heat Pipes

ACT Company Overview

- **ACT was Founded in January 2003.**
- **Headquartered in Lancaster, PA**
- **Current Number of Employees: 9+.**
- **Business Areas:**
  - Technology Development.
  - Engineering Services.
  - Standard Products
  - Custom Products

Relationship with Thermacore

→ **ACT and Thermacore/Modine Teaming Agreement in March 2003.**

- ACT receives ALL Liquid Metal Heat Pipe Projects and Future Business Opportunities from Thermacore/Modine.
- ACT and Thermacore/Modine will Jointly Pursue Business Opportunities in Cryogenic, Aerospace and Military Markets.
- Thermacore/Modine will Receive Preferential Licensing on Electronic Cooling Technologies Developed by ACT.

Past DOE/OFE SBIR Work Thermacore International Inc. [1989-2001]

- Heat Pipe Cooling of Faraday Shields [1989-1993]
  - **Developed high temperature/high heat flux Monel/water heat pipes.**
  - **ORNL tests showed favorable results for high RF applications.**
- Porous Metal Cooling of Gyrotron Cavities [1991-1995]
  - **Developed enabling high heat flux water cooling system using porous metal single-phase convective cooling.**
  - **Demonstrated 12 kW/cm^2 in representative SNL/PMTF tests.**
- Porous Metal Cooling of Klystron Collectors [1992-1997]
  - **Technology extended to large area, high total power applications.**
- Porous Metal / Helium Cooling of PFCs [1995-2001]
  - **Developed PMHX technologies for high heat flux gas-cooled devices .**
  - **Demonstrated 11 kW/cm^2 with a helium-cooled divertor mockup.**

Current Commercial Interests

Thermacore International, Inc.

- ACT and Thermacore will cooperate where possible to develop hardware and technologies that will continue to address and advance the plasma facing components applications.

- Thermacore's long term interest is to develop commercial products for the following :
  - Electronics cooling markets
  - Aerospace, military, medical, and automotive thermal applications
  - High heat flux cooling applications and thermal systems design
    - Extreme ultra-violet [EUV] sources

ACT Personnel Overview

→ **Experience:**

- Years of *experience* with Thermal Technologies: > 180
- Number of *patents* granted on Thermal Devices: > 50
- Number of *publications* on Thermal Technologies: > 200

→ **Track Record in Technology Commercialization:**

- Heat Pipes for Electronics Cooling
- Loop Heat Pipes for Space & Terrestrial Applications
- Copper/Water Vapor Chamber Heat Pipe Production Line
- First Pilot Production of Solar Stirling HP Receivers
- Liquid Metal Heat Pipe Products
- Compact Dual Impingement Air-to-Air Heat Exchanger

ACT Personnel – Technology Development

- Led > 300 Commercial and Government Funded R&D Programs
- First Color Picture Tube Development
- First Industry Team to Test Thermionic Converter in Reactor
- First Copper/Water & Lithium/TZM Heat Pipe Development
- First Flexible Liquid Metal Heat Pipe – Na @ 1000K
- First Liquid Metal CPL, Na @ 1000K
- First High Heat Flux Silicon Laser Mirror Cooler
- Metal Lined Composite Heat Pipe Envelope

ACT Personnel -Technology Development - 2

- → Highest Known HP Heat Flux, 126 kW/cm^2 - W/Li @ 1500K
- → First Vapor Fed AMTEC Development
- → First 75 kW$_{th}$ Solar Stirling HP Receiver
- → First Heat Pipes Designed for Server Applications
- → First LHP Made Outside the Former USSR
- → First LHP in Space Outside the Former USSR
- → First High Heat Flux LHP, 80 W/cm^2

ACT Key Technologies and Products

- **Heat Pipes and Loop Heat Pipes:**
  - Propylene, Ammonia, Methanol, Water, Cs, K, Na and Li.
  - Grooved, Mesh Screen, Sintered Powder Metal Wicks.
  - Al, Cu, SS, Monel, Inconel, Haynes, Ti, Mo, and W.
- **Pumped single and two-phase loops:**
  - Pumped Single-Phase Flow PMHX.
  - High Heat Flux Two-Phase Flow Loops and Cold Plates.
- **High heat flux cooling technologies:**
  - Modeling of Two-Phase Flows in Porous Structures.
  - Advanced Evaporator Designs.
- **Energy conversion:**
  - High Temperature Conversion: AMTEC, Thermionics.

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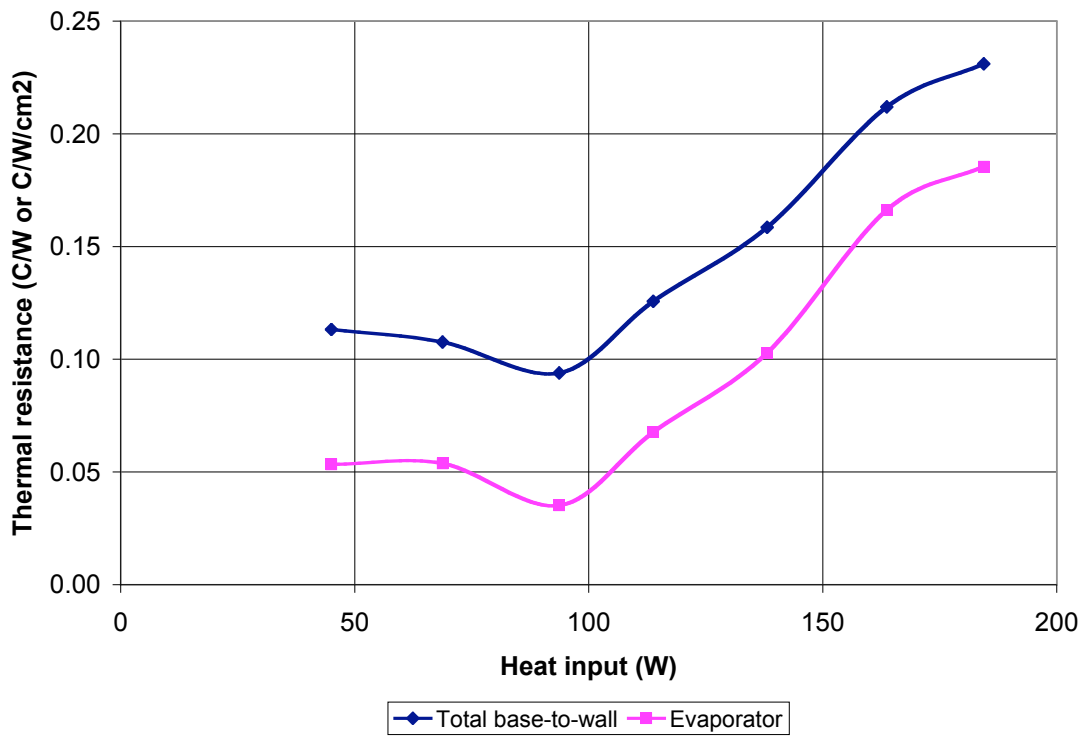
High Performance Heat Pipe Testing

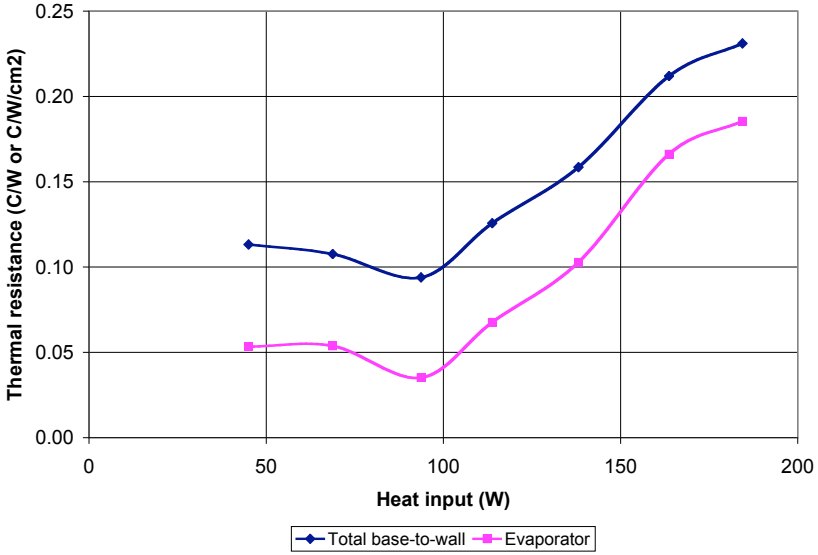
→ **Existing Copper/Water Heat Pipe Performance Characteristics:**

- Test Data (Thermacore - Feb. 2003).
- Tower Configuration.
- Heat Input Area: 1cm × 1cm.



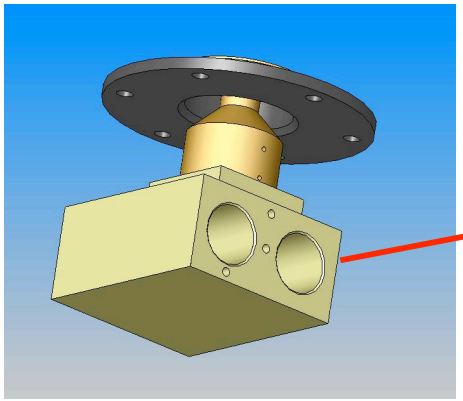
High Performance Heat Pipe Testing Conclusions

- → **Unacceptable Thermal Resistance at High Heat Flux**
- → **Evaporator Dominates, Particularly at High Heat Fluxes.**
- → **Future Trends:**
  - Higher Heat Fluxes: → 200 W/cm^2.
  - Lower Thermal Resistance: → 20% Reduction.
- → **Need Heat Pipe Evaporator Performance:**
  - 0.05^{O}C/W/cm^2 at 200 W/cm^2.

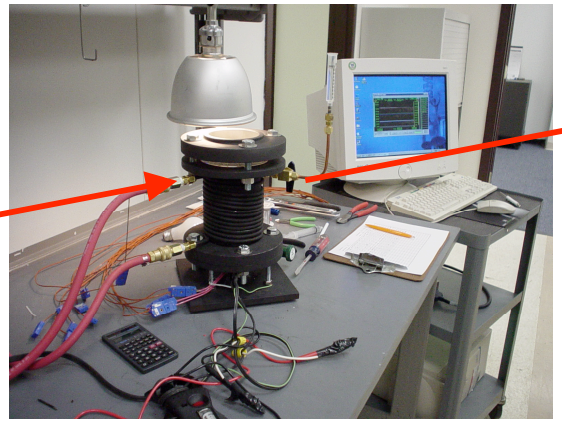


Advanced Heat Pipe Evaporator Wick Testing

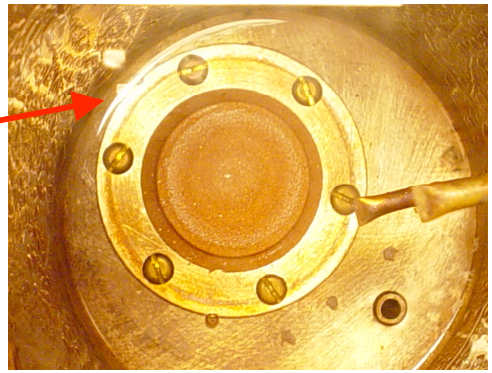
- **Joint Program Between ACT and Thermacore.**
- **Heat Input Area: 7mm × 7mm.**
- **Controlled Test Apparatus:**
  - Minimize Heat Spreading Effects.
  - Minimize Negative Impact of Instrumentation on Heat Flow Path.
  - Allow Visualization of Evaporation and/or Boiling



Test Article and Heater Block

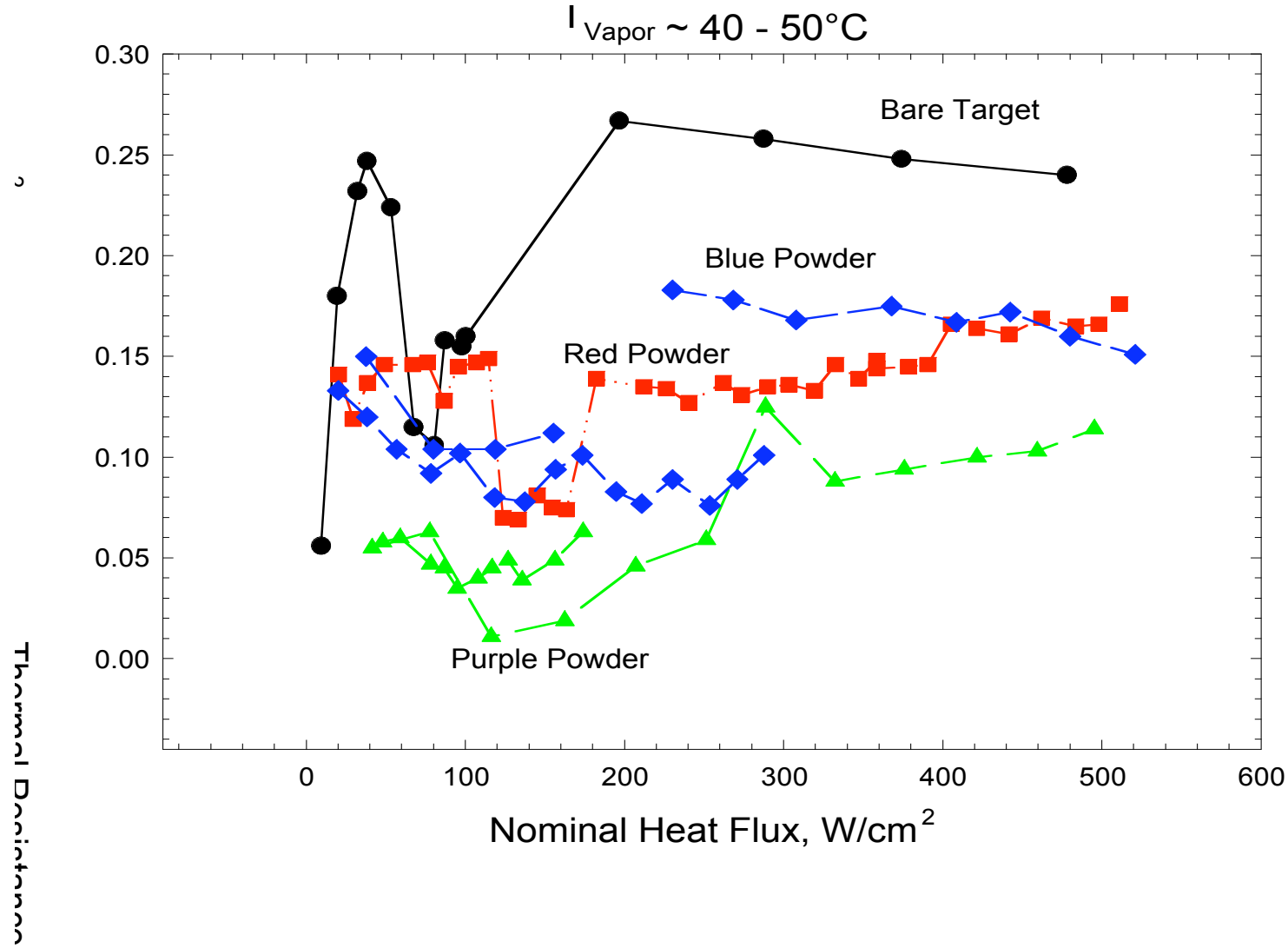


High Heat Flux Test Rig



Dry-Out Starts at the Center

Advanced Heat Pipe Evaporator Wick Testing - 2



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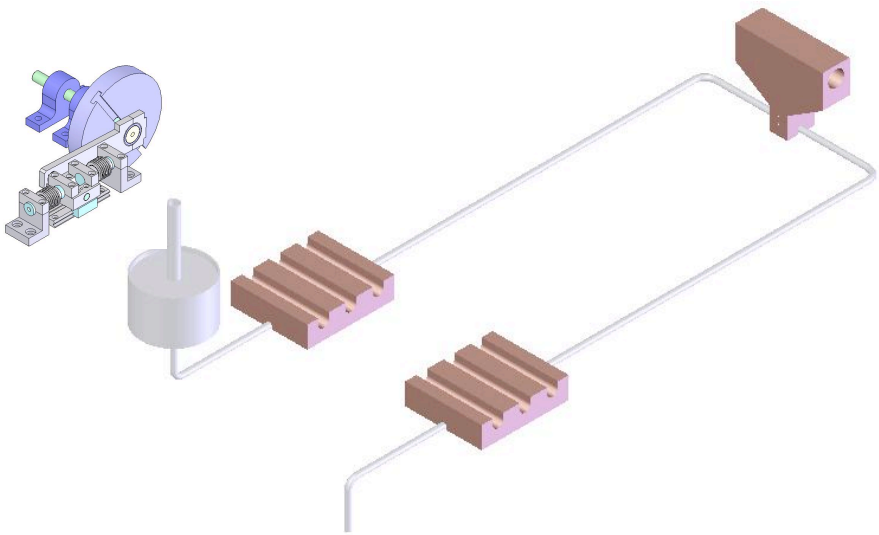
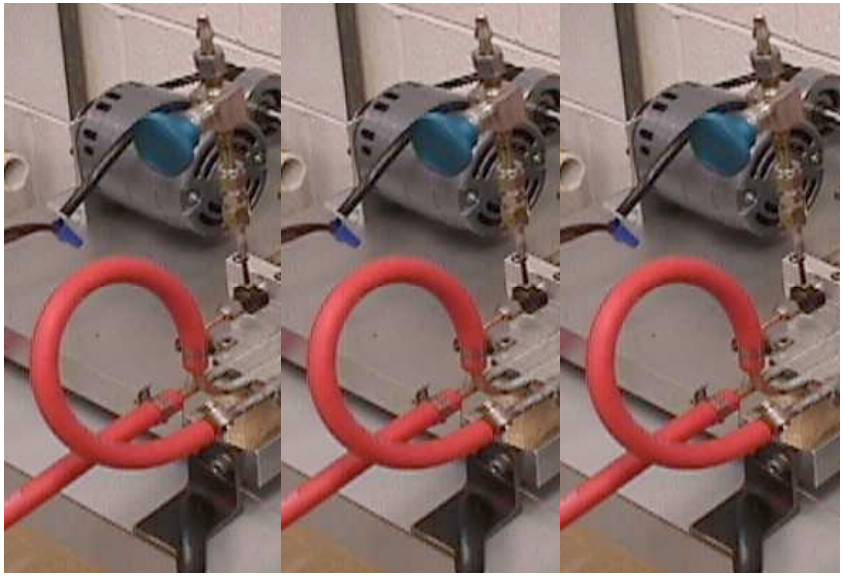
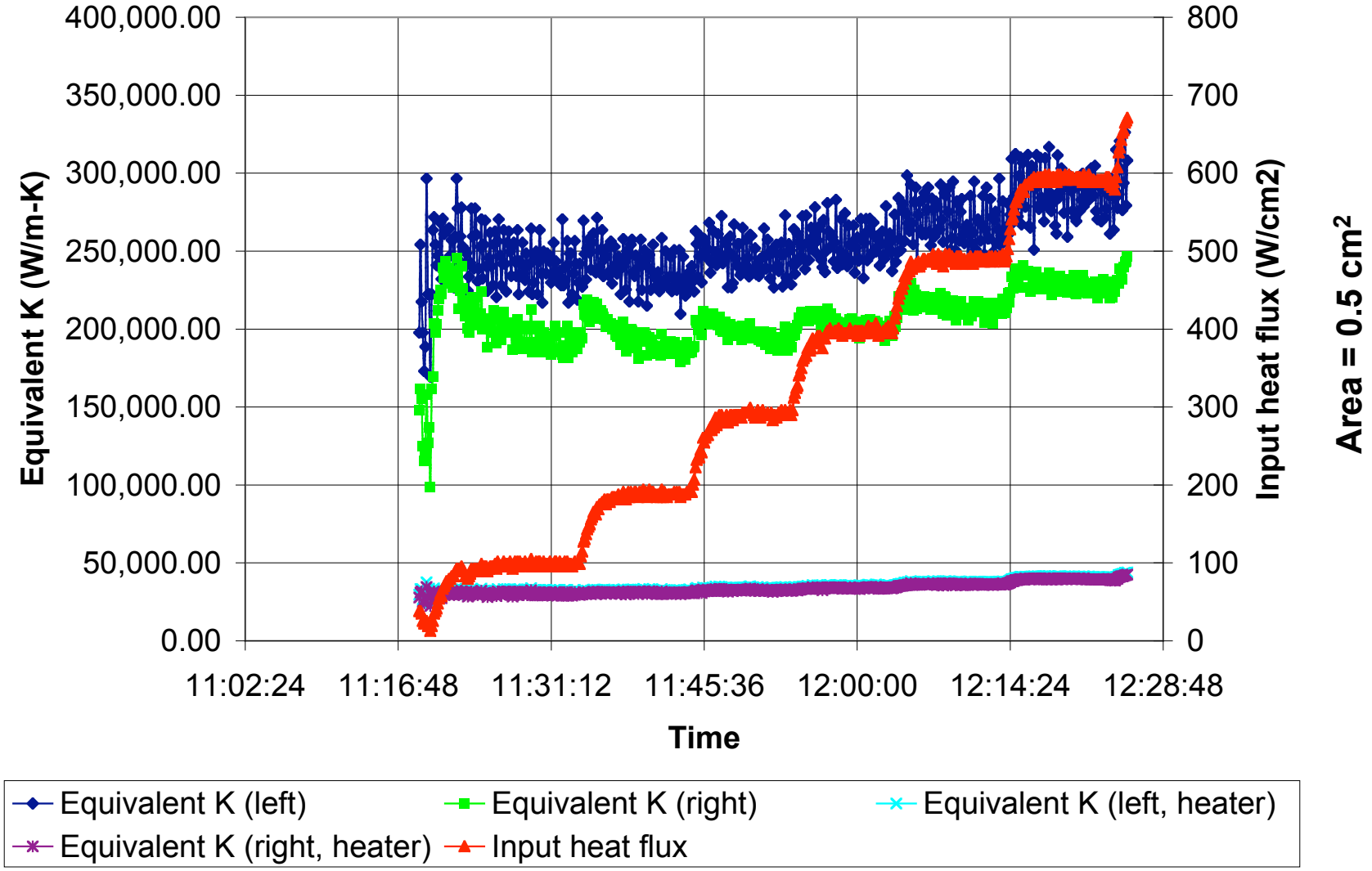
Oscillating Flow Loop Testing

- → Miniature Actuator(s) Oscillate a Single Phase or Two-Phase Fluid Inside a Loop.
- → Fluid Oscillations "Relay" Heat from Heat Source to Sink.



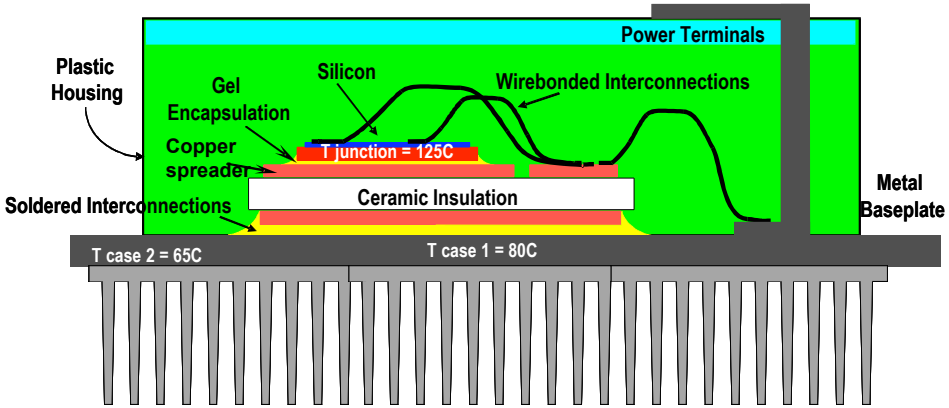


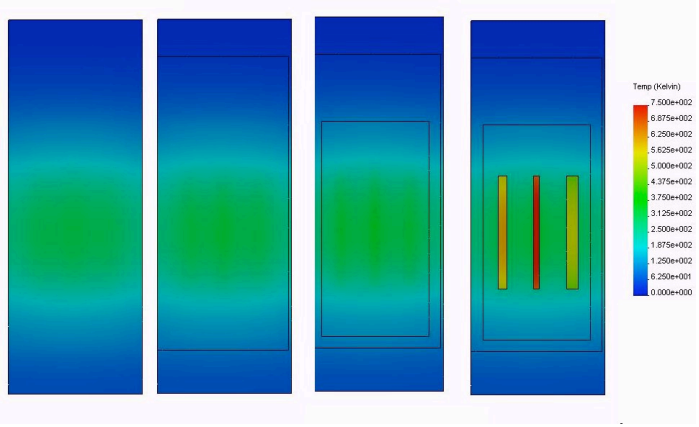
Oscillating Flow Loop Test Results

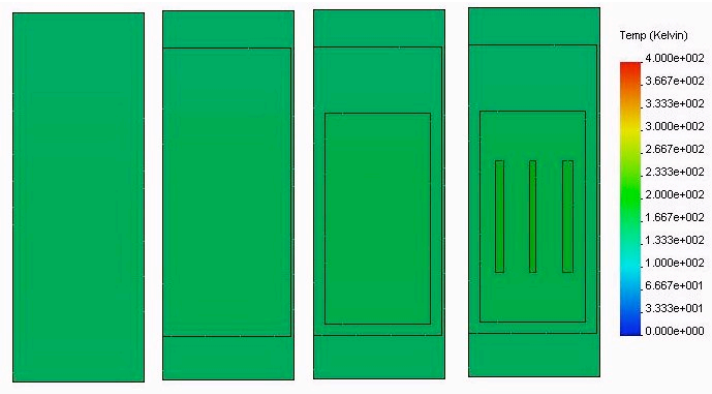


Oscillating Flow Heat Spreader Application

- → Replacing Copper Spreader and/or Package Case in High Power IGBT Modules.
- → Multiple, Discrete Heat Sources at Various Heat Fluxes.
- → Total Heat Load: 600W.
- → Maximum Heat Flux: 1,000 W/cm^2.







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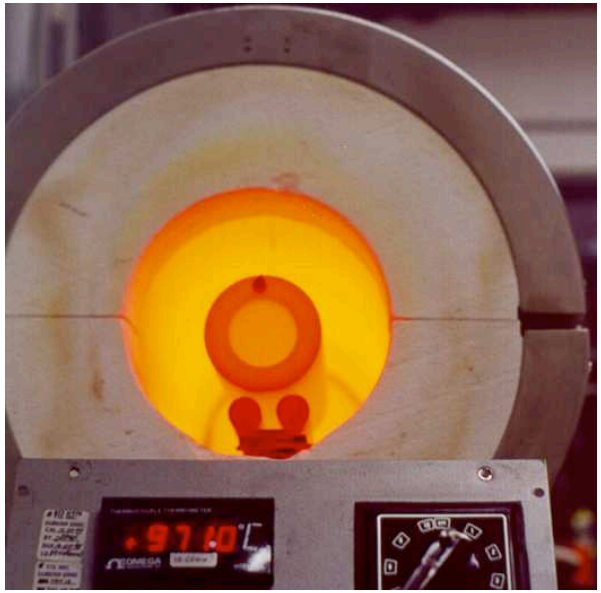
Liquid Metal Heat Pipe Products

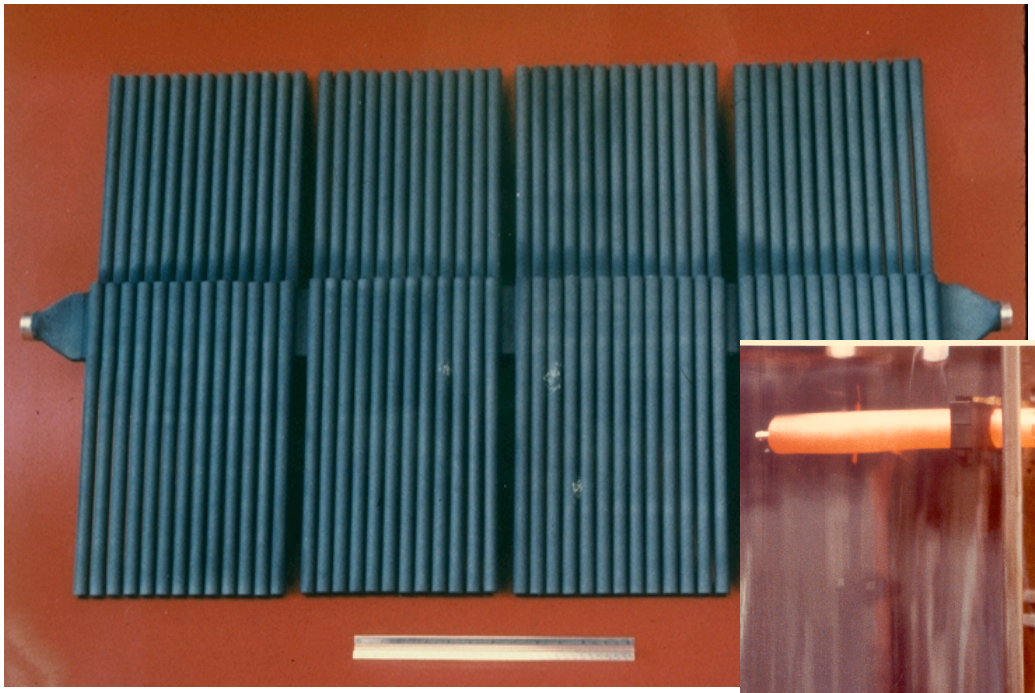


Isothermal Furnace Liners

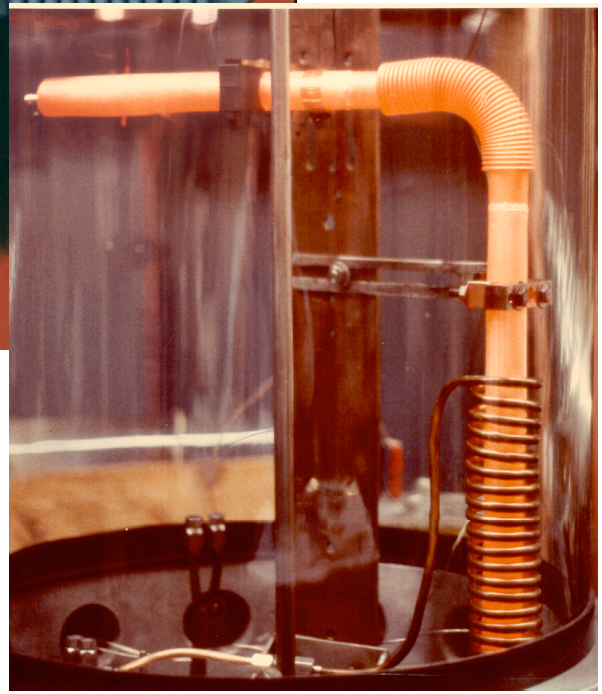
200 to 1,200 °C

Water, Cesium, Potassium, Sodium

Liquid Metal Heat Pipes - Heritage



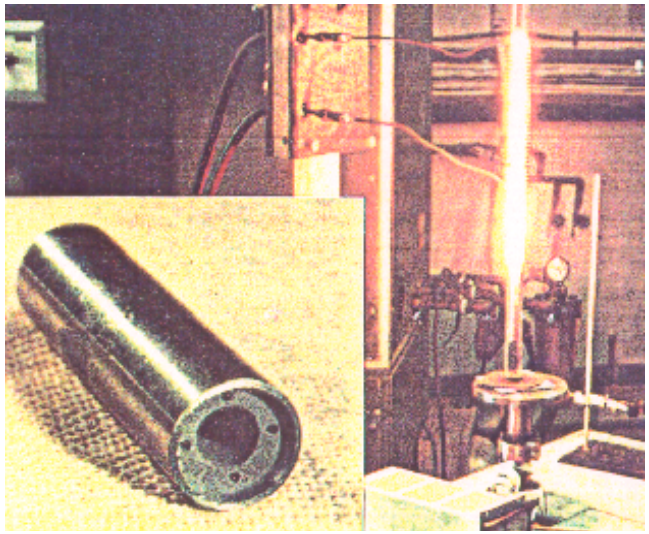
50, 1kW Na/SST Heat Pipes Mounted on a Section of Liquid Lithium Pumped Coolant Loop



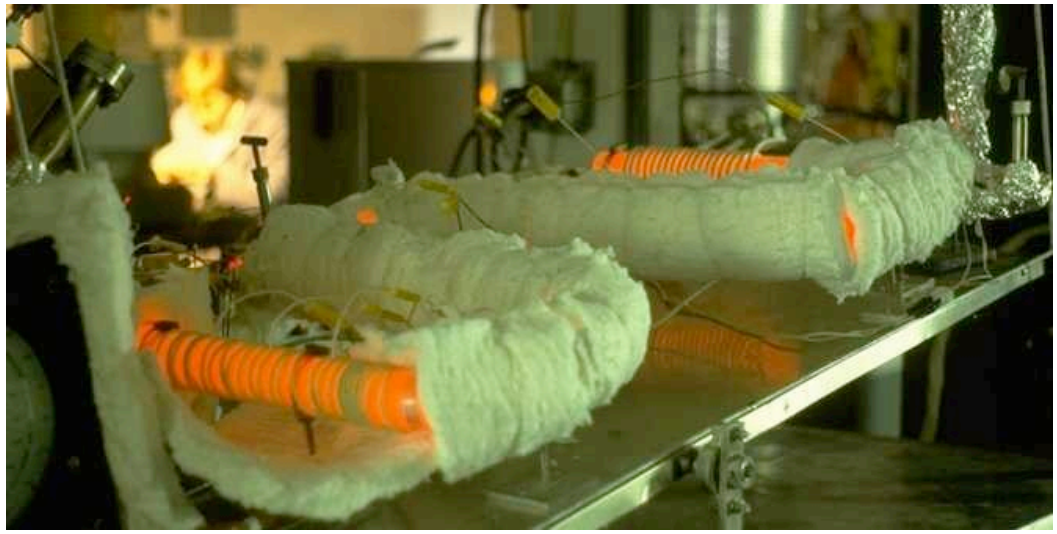
Flexible Na/SST Heat Pipe 2kW at 1000K

5.5m Long Na Radiator Heat Pipe -5 kW @ 1000K)

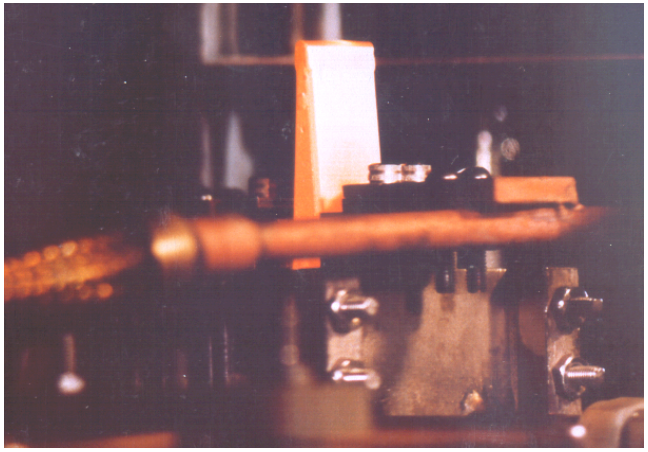
Alkali Metal Heat Pipes - Legacy



Mo/Li Heat Pipe - 6 kW @ 1800°C



Sodium CPL - 20kW @ 1,050K)



Engine Cowl
Leading Edge
W/Li Heat Pipe
1500 K - 126 kW/cm^2

Conclusions

- Advanced Cooling Technologies has the experience and capability to provide innovative thermal management solutions for Plasma Facing Components.

- Advanced Cooling Technologies can continue the work that was started with Thermacore – drawing on Thermacore's personnel, equipment, and facilities as a commercialization partner.